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Ground Truthing[1] for Forest Cover Loss Analysis

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Table of Contents

1

Context

The ability to monitor forest cover loss and to correlate loss with field interventions are critical to USAID's Strategic Objective #3 and to the M&E system for Madagascar's NEAP. Conservation of Madagascar's unique biodiversity is the principal objective of SO3 and one of the principal concerns of the NEAP. Most of Madagascar's unique biodiversity is found in the natural forests of the country. Monitoring forest biodiversity directly is a difficult challenge -- it is even difficult to get agreement amongst researchers as to what appropriate biodiversity indicators should be. In comparison, monitoring forest cover loss is a relatively simple task. Furthermore, it lends itself to automated or supervised image classification and change analysis based on satellite and or airborne remote sensors.

There have been a number of attempts to assess forest cover loss in the past. However, it is only in the past year that a serious attempt is now being made to develop forest cover loss assessment methodologies for use as an operation monitoring tool to assess, and improve on, NEAP biodiversity conservation strategies. A number of institutions are now actively developing forest cover loss assessment methodologies. These include FTM, CFSIGE, ANGAP and the USAID-funded PAGE Project. Of these, PAGE has taken the lead on developing ground truthing methodologies for two objectives – for improving the accuracy of the forest cover loss measures and for measuring the accuracy of the forest cover loss analysis.

However, although monitoring forest cover may be relatively simple when compared to the monitoring of lizard populations in a remote forest, it is still not simple. It requires a an appropriate, balanced mix of remote sensing and image processing specialists working in partnership with experienced field resource specialists. This partnership will be the most effective when those directing the work in the field, themselves, have a basic understanding of the remote sensing systems being used.

This present report is by a consultant with a foot in both worlds. The consultant spent nine years from the mid-70s to the mid-80s working in remote sensing applications, mostly to forest and wetlands ecosystems. This often involved a considerable amount of time "ground truthing" in remote roadless areas of difficult access (Alaskan coastal wetlands, peatlands, Mississippi floodplains) where a lot of the "ground truthing" had to be done from low altitude overflights. Highly successful use of low altitude, high oblique (horizon visible) 35-mm aerial photographs taken from these overflights was made as interpretation aids in these roadless areas.

The consultant also has a wide range of field experience in Madagascar going back to 1987. The consultant does not pretend to be a specialist in computer-aided image classification or in the statistical sampling systems for putting confidence intervals on estimates of forest cover change. The consultant's greatest strength may be in helping to identify ground truthing methodologies that both meet the needs for precision required by the validation specialists and that are realistic, doable and of reasonable cost.

2 Key Challenges in Measuring Forest Cover Loss

If effective, affordable methodologies for measuring forest cover loss in Madagascar can be developed, then a whole range of fascinating range of applications present themselves. One will have the ability to make very specific measures of the impact on forest cover loss of a whole range of different biodiversity conservation strategies tested throughout the country over the past ten years or so. A few of these applications are presented in Appendix C in a small document developed by the consultant.

First, however, one must develop the effective, affordable methodologies for measuring forest cover loss. There are two principal challenges:

1. Objective 1. Develop methodologies for conducting the most accurate possible analysis of forest cover change in targeted areas, within reasonable levels of cost. This basically comes down to being able to correctly classify each part of each image as Forest or Non-Forest.

2. Objective 2: Develop cost effective, yet statistically sound, methodologies for assessing the accuracy (the amount of error) of the analysis of forest cover change. Anyone can make an estimate of the amount or of the rate of forest cover change. But, to be credible, one needs to provide evidence of the accuracy of the estimate. A small number of countrywide, or broad regional, remote sensing-based estimates have been done in the past. Several institutions are currently working on forest cover change analysis for specific sites. But no one has yet done a statistically-based validation of any of these estimates. It is critical that validation methodologies meet international standards – that the results can be defended against the inevitable critics.

One needs to develop and apply a sampling scheme to determine how accurately the imagery of the two dates was classified into the two Forest and Non-Forest categories. It is necessary to collect field reference data of specific sampling sites. This type of field reference data is called validation data. One must develop methodologies for collecting validation data that will show whether or not the sample sites were correctly classified as Forest or Non-Forest, for both of the dates of the analysis.

Need for Clear Definitions of Forest/Non-Forest

To analyze forest cover change, one needs to adopt a clear definition of Forest and Non-Forest. This has not yet been done, although Ned Horning has conducted a preliminary analysis of forest cover change on three corridors under contract with PAGE. The three corridors include two USAID priority conservation areas (the Moramanga to Onibe Corridor and the Ranomafana to Andringitra Corridor) and a control corridor (Anosybe An'Ala).

Horning conducted this analysis based on prior experience in Madagascar combined with his expertise in remote sensing and image analysis. Horning reduced all cover types to his two classes of Forest and Non-

Forest. This is deemed appropriate for the purposed of this study. Horning advances a theoretical definition of Forest as "...loosely defined as an area of trees greater than 7 meters in height with greater than 30% crown closure" in his May report. This definition needs to be reviewed and refined into a more meaningful and usable definition. The following criteria for a workable definition are proposed:

- It should meet USAID's requirements as a key indicator for SO3;
- It should be usable and acceptable to all the NEAP partners;
- It should make good sense to field resource managers and biologists;
- It should correspond to spectral response pattern differences that are discernible on the satellite imagery used for the forest cover change analysis.

Key points to be considered include the following:

- The main interest of the forest cover change analysis is to be able to quantify the loss of natural forest through clearing for agriculture;
- Clearing for agriculture is clearly the principle cause of forest cover loss in the eastern, humid forests of Madagascar.
- Conversion to agriculture represents a drastic, radical change to the forest ecosystem from which it would require long periods of time to recover. Most of the nutrients from the ecosystem are released and are lost. All the duff layer is mineralized and lost. Over 95% of the tree species from the natural forest do not commonly regenerate in the first fallow vegetation.
- It is broadly believed that nearly all forests cleared for agriculture in the last 30 years or so have never been allowed to develop into secondary forests. (This is a hypothesis to be tested during ground truthing fieldwork.) Forest cleared for tavy is invariably fallowed after one to several years of cultivation. The fallow vegetation is almost never allowed to develop into secondary forest – it is cleared again for cropping before this can occur. The problem of distinguishing forest from secondary forests that have developed from land that has been cultivated in the past 30 to 50 years is so rare as to be trivial – it is probable that this is not a problem that we have to deal with.
- In the strictest sense, there is probably no truly natural forest in Madagascar. All forests have been modified, or degraded, to some extent by man's influence.
- There are all degrees of degradation. There are no clear cut-off points. One can not readily distinguish slightly degraded from moderately – or perhaps, heavily degraded – forest from satellite imagery.

The following definitions are proposed for the three corridor study areas (a broader definition will need to be developed later to include the dry forest, spiny forest and mangrove forest areas) to serve as the basis of debate in the development of commonly agreed upon definitions:

- Forest is a vegetation type dominated by native tree species that has not been cultivated in the last 30 years. (Or could we say 50 years? If this statement is valuable for the past 50 years, then the 1950s aerial photography could be used to validate the Non-Forest class.)

  Other associated characteristics – each them are open to debate:

  - A Forest has not been planted by man – Eucalyptus and pine plantations do not qualify.
  - Stands of invasive species do not qualify under this definition of a Forest (Can all stands of invasive species be distinguished from Forest on TM imagery by their spectral response patterns? Horning thinks this will be difficult – I think that most stands of invasives are homogeneous enough – and far enough removed from the Forest/Non-Forest border – that they will be distinguishable on the TM imagery)
  - A Forest has a natural duff layer that is at least xx? cm thick (This is an hypotheses to be tested – do any humid natural forests occur that do not have a duff layer? Is it possible for a fire to consume/destroy the duff layer without killing most of the overstory trees? Can the presence or absence of a duff layer be used as a defining characteristic to distinguish between Forest and Non-Forest? The presence or absence of a duff layer is clearly not something that can be detected directly from TM imagery, but it may serve as a defining characteristic for ground crews.)
  - A Forest has not burned in the last xx? years. (How should we classify stands that have been burned? Does the humid forest recover after fire? Do all fires in the humid forest kill most of the forest canopy? What will become of the numerous humid forest stands that have burned in the last six years? Should they be considered as Forest or Non-Forest? Will they recover as forests if left alone? How widespread is this phenomenon? The author has seen a number of humid forests whose canopy has been completely or largely killed by fire. But the author has not had the opportunity to check on what is regenerating under such stands. If the regeneration is dominated by native species form the stand that was killed by fire, one could argue that this should still be called a Forest. Can forests whose canopy has been completely or mostly killed by fire be distinguished on the TM imagery? If so, this would be an important phenomenon to monitor in the future using TM/satellite imagery)
  - Stands that have been logged still qualify as Forest as long as agriculture or fire did not follow the logging. Logged stands still qualify as forest even if 30-50% or more of the canopy has been removed by logging. (How common is heavy logging that removes a major portion of the canopy? Are they associated primarily with charcoal making? Serge Rajoabelina reports

that some humid areas south of Anjozorobe were being clearcut for charcoal in recent years. Can such areas be distinguished on the imagery? If they can, this could be an important tool for the new *Observatoire* to use for monitoring whether or not forest harvest occurs within areas covered by legally issued *permi d'exploitation.* Should very heavily logged areas still be considered to be Forest?)

- Non-Forest includes all cover types that don't qualify under the definition of Forest.

  Non Forest includes:

  - Active fields, including all areas planted to perennial tree crops
  - Fallow
  - Tanety grasslands
  - All areas dominated by invasive woody species and other perennial species
  - Water bodies and wetlands dominated by herbaceous vegetation;
  - Bare soil and rock outcrops
  - Villages, urban areas and all other "built-up" areas.

3 Ground Truthing for Characterization and for Validation

Ground truthing consists of gathering reference data on the field conditions in areas being studied. PAGE has need of two basic types of field reference data for their forest cover change analyses:

1. Characterization reference data
2. Validation reference data

Characterization data is needed for both supervised and unsupervised image classification. For supervised analysis, sites of known cover type are needed so that the classification software can correctly classify pixels that have spectral responses similar to the known cover types. For the current forest cover change analysis, computer software is used to classify each portion of the satellite image as Forest or Non-Forest. This is done using the recorded spectral response of each cover type included in the image being analyzed. Each cover type has a statistically definable range of spectral response values. Sites of known cover type are used to “train” the software to classify each land area by its digital spectral response values. The reference data that is used to “train” the computer software to correctly distinguish between Forest and Non-Forest is called characterization data.

For unsupervised image classification, the classification algorithm groups pixels of similar spectral response into clusters. Characterization reference data is then needed for each of these clusters to determine what cover type they correspond to – in this case to determine whether they are Forest or Non-Forest.

Validation data is needed to assess the accuracy of the classification or analysis that has been done. For the forest cover change analysis, one must gather validation data to determine what portion of the field sites were correctly classified as Forest and Non-Forest for each of the two dates of the imagery used. You’ve done the analysis and now you want to know how meaningful it is. You want to be able to defend the results with those who may challenge their validity. To do this, one uses a statistically based sampling scheme to locate plots in each of the different change classes. Then validation data is gathered on the ground or from the air or from other sources of information to determine if each sample was correctly classified for each date. The results are analyzed to give a quantitative measure of accuracy accompanied with a confidence interval for the measure.

There is no inherent difference in the nature of characterization versus validation data. They can be collected at the same with training (characterization) data kept separate from test (validation) data. In fact, to save time and money, training data **can** also be used as part of the test or validation data. Accuracy assessments using the training serve as an upper bound to the accuracy of the classification performed. If test accuracies (using test data kept separate from training data) are very close to training accuracies (calculated using both training and test data) are very close, then one did a good job training the classifier algorithm – one did a good job distinguishing between Forest and Non-Forest. If the test accuracies are way below the training accuracies, then one did a poor job.

4 Methodology for Characterization Reference Data Collection

Field reference data is necessary for an accurate analysis of forest cover loss. The technical term for this type of data is characterization data. One must identify geographically referenced sites of known cover type or "character" – in this case, sites that are known to be either Forest or Non-Forest. One must identify sites that were known to be either Forest or Non-Forest at the same point(s) in time at which the imagery used for the analysis was captured. Both of these cover types are characterized by a statistically quantifiable range of spectral response values – of the amount of reflectance in each of the spectral bands recorded by the Landsat Thematic Mapper sensor used for the forest cover analysis.

An outline of the methodological steps for the collection of characterization data is first presented here. Then details on these steps are subsequently developed. The outline follows:

1. The collection of characterization data should focus primarily on atypical sites. This should be done in two ways – a) by targeting sites identified by the image analysis specialist as being difficult to classify – as areas of uncertainty, and b) by targeting sites that are strongly suspected of having atypical spectral response values by those most familiar with the field conditions in the areas of study.
2. The areas of uncertainty that were identified during the preliminary analysis of forest cover change by Mr. Horning should be targeted as prime sites for collection of characterization data. Horning should be requested to geo-reference these sites and to provide a brief description for each site of the nature of the spectral response patterns that lead to the uncertainty – along with any hypotheses he may have as to the causes. (Upon request, Horning has already supplied such a list of sites. One will need to determine if the geo-referencing of the sites is adequate. Horning has not yet been asked to provide the descriptions and his hypotheses);
3. Develop a list of potential atypical cover types or "anomalies" that may produce spectral response patterns that are difficult to classify accurately (See the preliminary list presented in "Characterization of Probable Anomalies" below.)
4. Develop a network of contacts with people most knowledgeable about the three corridors. Work with them to complete the list of anomalies and to identify geo-referenced field sites representative of each of these anomalies, or of as many anomalies as possible (This task is much more difficult than Step 3) ;
5. Make a determination of the most efficient means of obtaining characterization reference data for the specific sites identified in Steps 2 and 4. In general, the procurement of aerial photography/imagery of geo-referenced sites will probably provide the best reference data for characterization of each site. The most efficient method would be to take aerial photographs of each site, using a GPS-linked camera with geo-referencing system of suitable accuracy.
6. Locate an institution/business/individual with a geo-referenced aerial photography system who can overfly and produce aerial photography of the two types of geo-referenced sites referred to above;
7. If no geo-referenced aerial photography system is available locally,
8. Conduct detailed planning of the overflight(s) for the three corridors;

9. Conduct the overflight – procure the photography/imagery;
10. Interpret the photography obtained, prepare a written report and send this to Horning or others who are conducting the forest cover change analysis. The report should classify each site as Forest or Non-Forest and should provide those doing the image analysis with the most useful information for redoing the preliminary analysis.
11. Redo the forest cover change analysis, this time conducting a classification of all imagery used, using the characterization reference data provided.

■ Characterization of Areas of Uncertainty

It is not efficient to collect characterization reference data in a systematic fashion based on a grid or other sampling scheme. Characterization reference data collection should concentrate on area of uncertainties and on areas of known anomalies. The areas of uncertainties are areas that Horning had difficulty in classifying based on his field experience and theoretical expertise. Horning has already provided us with very small-scale maps on which he has identified his principal areas of uncertainties. We need to determine whether he has located them accurately enough for use in planning the collection of characterization data.

Another set of sites for the collection of characterization data could come from a comparison of the forest cover loss conducted by FTM (and others that are working on the same sites) with that done by Horning. Frank Hawkins' March 28 e-mail to Ned Horning specifies that FTM would also measure forest cover loss at fours sites in eastern Madagascar including the three USAID priority corridors (would the three include the Anosybe An'Ala control corridor). If FTM has already conducted this analysis, it could be very instructive to compare their results with Horning's preliminary classification to identify specific areas where the two analyses do no agree. The areas of disagreement should be targeted as important areas for gathering characterization reference data.

We should brainstorm together to make an initial attempt to identify the causes of these areas of uncertainties identified by Mr. Horning. Possible sources of information/knowledge/expertise for doing this are the following:

- Check these areas against the IEFN map,
- Check these areas against the imagery used for the IEFN maps – is it available? Where? Under what conditions?
- Check these areas against the itineraries of the recent video overflights. For uncertain areas covered by this overflight:
    - Check the recollections of Frank Hawkins, Martin Nicoll and any others who participated;
    - Check the video coverage itself wherever it coincides with Horning's uncertainties;
- For all areas of uncertainties that correspond to permanent natural features, imagery of any date should be useful in providing characterization reference data. This would include aerial photography of any date. For vegetative anomalies, color infrared photography would be by far the most instructive. Black and white infrared would be a next-best choice. Convention black and white panchromatic photography would be the least useful. We need a complete inventory of all available aerial photography and imagery for each corridor as well as information on conditions of access to each set of photography.

- Check the areas against the field knowledge of any one familiar with these areas. These could include taxonomists who have participated in RAP surveys, field project staff of LDI or others, ANGAP/AP staff, Eaux et Forêts agents, pilots, Phelps Dodge staff, others.

■ Characterization of Probable Anomalies

Characterization data should include data on sites that, based on our knowledge of actual field conditions/cover types and our knowledge or remote sensing classification systems, we judge will probably present difficulties in classification as Forest or Non-Forest. These are untypical areas or anomalies that will probably have a spectral response pattern that is probably near the margins of the statistically typical spectral response for either the Forest or the Non-Forest classes.

Atypical cover types will probably include the following:

- Rock outcrops,
- Atypical forest/natural vegetation types that are atypical because they occur on shallow soils/high altitudes/highly acid soils/etc.;
- Recently logged areas, especially areas where a high percentage of the forest canopy has been removed – say, over 30 %. (An interesting secondary question is whether or not recently logged areas can be detected from TM imagery. If so, this could be useful for the Observatoire National for monitoring the respect of the logging concession permit system)
- Areas of standing dead forest, or partially dead forest, killed by forest fire (a seemingly increasingly common phenomenon)
- Areas disturbed by mining or mineral prospecting (Phelps Dodge, ruby mines)
- Cyclone damage
- Very old fallow areas – true secondary forest and all the potential gradations between very old fallow and active tavy. Are there any fallows in of the three corridors that might be confused with forest? Is there such a thing as young secondary forest in these areas?
- Agriculture practiced under a full to partial canopy. Does this occur in the three corridors? This could potentially be a major cause of error, if it exists in the three corridor areas? This does occur at Amber Mountain in the north. The DG MinEnv claims it is widespread in the littoral forest on the east coast. Were any cases of this picked up by the recent video overflights?
- Dense eucalyptus plantations of varying age/height, or other man-made plantations, that might have a spectral response pattern that might be confused with that of natural forest;
- Some of the more lush mixed gardens on the richer soils of the lower slopes (the tanamboly) in the tavy zones.

Several of these anomalies are strongly time-dependent (cyclones, logging, fires). We must be very careful to ensure that the time frame for field occurrence of these anomalies corresponds to the date of the imagery that Ned is using for the analysis. The precise dates of the imagery used by Horning are presented in his report.

Once again, it is the people who know each area best who will generally be in the best position to identify areas of anomalies. PAGE will have to decide how far they want to pursue such information sources.

- Current characterization reference data collection

At this point, it seems that the most efficient means of collecting characterization reference data would be with one or more overflights to collect geo-referenced aerial photography of these areas of uncertainties and of identified anomalies. The geo-referencing of characterization data does not (generally) need to be as precise as that for validation data. If the photography is referenced within a few hundred meters, this will probably be sufficient in most situations – if everything within the three hundred-meter radius is composed of the same cover type (Forest or Non-Forest) or if the anomaly is the only anomaly present within the 300 meter radius. . This is certainly true for photography/observations to be taken within the relatively broad areas identified as uncertain by Mr. Horning.

Aerial photography could also be used for much of the validation data, even aerial photography with a geo-referencing error or the order of 300m, if there are other recognizable features on the photography that can be indexed to the TM imagery and/or the forest cover change map.

See Appendix A on Options for the Procurement of Geo-Referenced Aerial Photography. As best this consultant was able to determine, no service in Madagascar is presently equipped to fly geo-referenced aerial photography for PAGE. This consultant recommends that PAGE procure a suitable system themselves, or better, that they assist FTM or a private business to equip themselves with a suitable system – by guaranteeing them a minimum amount and/or through helping to line up other clients who are also working on forest cover loss analysis.

- Planning the Overflight

The report "Survols de Aires Protégées et des Ecorégions – Rapport Préliminaire – secteur centre-est – 16 à 18 novembre 2000" provides very useful technical advice for planning overflights. Sites will be located using the GPS system on the airplane used for the flight.

- GPS coordinates of all sites to be flown must be prepared in advance of the flight;
- An itinerary to cover all the sites in a logical sequence should be prepared. This should be done in consultation with the pilot.
- Altitude, flight speed and other parameters should be planned as a function of the type of camera, focal length, etc. used for the flight;
- One should be able to verify from the air that the photography is being taken over the correct position. Imagery, air photos, maps, etc. should be prepared to take along on the flight for verification of the location of each site located with the onboard GPS system. Each site should be marked on these reference documents;

Interpretation of the Aerial Photography for Characterization

Once the aerial photography for characterization reference data is obtained, it should be first analyzed by the ground truthing advisor and others are the most familiar with each area. They should concentrate on the following:

- For areas of uncertainty identified by Mr. Horning, they should provide an interpretation of the cover types and should attempt an explanation for the atypical spectral response. If they cannot accurately determine the nature of the cover types from the photography flown, the groundtruthing consultant should take a team in on the ground for a more accurate characterization;
- For air photo coverage of specific anomalies, the Groundtruthing consultant should provide an accurate identification of the anomaly on the photography accompanied by a description of the nature of the anomaly.

The photography with the above information should be sent to Mr. Horning or whoever is doing the image classification.

■ Characterization for the 1993 Imagery

The following assumptions are proposed for characterization for the 1993 imagery:

- Any site that is currently Forest was also Forest in 1993;
- Any site that was Non-Forest on any aerial photographs taken between 1970 and 1993 can assumed to have been Non-Forest also in 1993 (In a personal telephone communication, Ned Horning agreed with this assumption);

5 Validation Reference Data Collection

Methodology/Steps

We make the assumption that the accuracy of the preliminary analysis of forest cover change is quite high -- Mr. Horning feels quite confident of this. We can proceed to plan and collect validation data based on this preliminary analysis. We would do this recognizing that a few of the sample points used may have to be discarded/replaced after the reclassification/final analysis is conducted by Mr. Horning based on characterization data to be provided by to him by PAGE. The proposed methodology follows:

1. Define the area to be sampled through the preparation of an accessibility mask for each of the three corridors covered by the preliminary forest cover change analysis. See the discussion below describing what an accessibility mask is and what factors should be taken into account in defining it.
2. Decide on the number of validation samples for each change class for each of the three corridors. Sample size should be based on estimates of costs, desired levels of accuracy and budgets available. There should be an equal number of plots in each of the two change classes (no change and change) for each corridor. The No Change class includes sub-classes, a) Forest to Forest and, b) Non-Forest to Non-Forest. The Change class includes only Forest to Non-Forest. (The reverse is assumed to not happen). The number of sample plots for the No Change class should be equally divided between the Forest to Forest and the Non-Forest to Non-Forest sub-classes. See the discussion below on sample size.
3. Choose and apply a method for the location of sample pixels within the area to be sampled. Mr. Horning says there is a variety image processing software programs that will perform or simplify this function. Examine each pixel to see if it is part of a contiguous 3x3 pixel block that is composed of 9 pixels of the same change class. Discard each sample pixel that is not surrounded by 8 pixels of the same change class. Replace each discarded pixel with the closest pixel of the same change class that is surrounded by eight other pixels of the same change class. Continue the replacement process until one has the full number of desired sample pixels for each cover change class for each corridor. If PAGE intends to continue to make use of the services of Mr. Horning, then this consultant recommends that Mr. Horning do the sample site locations and the pixel replacements for PAGE.
4. Develop a plan for collecting validation reference data on the sample units for each corridor. Sample units should be split into two categories – those for which validation will be attempted first by aerial photography and/or aerial observation through a planned overflight and those for which one will collect the validation reference data directly on the ground. See the section below, Categorization of Sample Units for Reference Data Collection.
5. Plan and conduct an overflight to take aerial photography of those sites than can potentially be validated with aerial photography (especially the Forest to Forest sites);
6. Develop and test methodologies for determining the 1993 cover type condition (Forest or Non-Forest) of sample sites -- see the Section on Validation of 1993 Cover Type Conditions below.
7. Plan and conduct on the ground validation for those sites that need to be validated on the ground – especially the Forest to Non-Forest and some or all of the Non-Forest to Non-Forest Sites. Prepare and use standardized data collection forms for ground observations.

8. Summarize data and calculate the accuracy of classifications – or, alternatively, organize data and photographs and send to Mr. Horning for accuracy calculations.

- Accessibility Mask

The ground truthing consultant should play the lead role in defining an accessibility mask for the collection of validation data for measuring the accuracy forest cover change analysis. The accessibility mask is a tool to eliminate portions of the study area that are judged to be too difficult of access – too costly in terms of budget and/or time, to include in the area where validation samples will be collected. Sampling will only be conducted in areas that are of relatively easy access. For example, most of the eastern side of the Moramanga to Onibe Corridor is believed to be of very difficult access.

Use of an accessibility mask is done primarily as a matter of necessity. Ideally, all of each corridor would be sampled – the sampling scheme would be conceptually "pure". When one uses an accessibility mask, one must make the assumption that the change in forest cover is the same in both the sampled and the unsampled areas. One should always seek ways to either confirm or disprove this assumption.

Some of the factors to consider in defining the mask, i.e., in delineating the area that will not be sampled, are the following:

1. The network of roads that are passable by motor vehicle during the dry season (We are assuming here that the ground truthing will be done during the dry season.) One should determine what means of transportation will be used by field crews – all terrain vehicles, motorcycles, bicycles, boats, ox carts, etc.) One will need to address the obvious question of how to determine which roads are passable. The question may be obvious, but the means of finding the answers may not be. One will have to pursue various sources of information – especially from people most knowledgeable about each zone.

2. The nature of the terrain to be traversed on foot, and the amount of time required and the difficulty for each type of terrain (tanety grasslands, tavy field and fallow, natural forest), especially as conditioned by the steepness of the terrain. Prevailing weather conditions may be another factor. For each type, or combination of types, of terrain, one should define practical guidelines, based on actual field experience, for the maximum distance from the nearest road access point. For example, a maximum of 25 km across a tavy/fallow mosaic on gentle to moderate slopes plus 5 km of tavy/forest mosaic on very steep slopes. Slopes can be derived from topographic maps or digital terrain models.

3. Natural barriers will need to be given special consideration, such as escarpments, wetlands and major streams.

The ground truthing consultant should make estimations of cost and time needed and should propose options for the accessibility mask for each zone. Horning and/or USGS should be consulted on the suitability of these options based on statistical sampling implications. PAGE and USAID should choose amongst these options based considerations of budget and time and adequacy of the sampling options.

These same considerations should also go into the choice of the number of sampling plots for each corridor.

■ Categorization of Sample Units for Reference Data Collection

Validation sample sites can be categorized as a function of the means of collecting validation reference data as follows:

- One should be able to collect validation reference data for nearly all of the Forest to Forest sample sites from aerial photographs to be taken from overflights;
- All of the Forest to Non-Forest sample sites will probably have to be validated on the ground;
- For the Non-Forest to Non-Forest samples, they will probably all need to be validated on the ground except for sites that can be shown to have been Non-Forest on any aerial photographs taken between 1970 and 1993.

If a suitable geo-referenced aerial photographic system can be accessed, then one should be able to use aerial photography for validation reference data for nearly all Forest to Forest classes. Sample sites classified as Forest on the 2000 image and that are right on the border of the Forest and Non-Forest interface and that may have to be ground truthed. Forest samples that cannot be adequately located on the aerial photography or that cannot be positively identified as to cover type can then be validated on the ground.

■ Geo-referencing for Ground Validation

Horning has recommended that sample points will be located at the center of a pixel that sits at the center of a square map unit that is 3 x 3 pixels in size. Only map units comprised of nine pixels of all the same cover type will be used for the sampling. As each pixel is 28 by 28 meters, then the center of the center pixel is located on 42 meters from the edge of the sample map unit.

However, Mr. Horning estimates that the average geo-referencing error on the forest cover loss map is about 50m. This is already greater than the 42-meter distance from the center of the sample map unit to the border of the map unit. Therefore, even if one used a GPS unit with no geo-referencing error to locate a sample point, one could not be sure that one would fall within the sample map unit. This is especially so given the fact that half of the pixels on the forest cover change map will have a positioning error greater than 50 meters.

PAGE needs to go back to consult Mr. Horning, and others, to determine if a 3 x 3 pixel sampling map unit is actually large enough – or if one needs to go to a 4 x 4 pixel map unit or larger. This is a question for the remote sensing and accuracy assessment specialists to answer.

■ Validation of 1993 cover class

Potentially the most difficult challenge in gathering the validation data is the determination of the cover type in 1993. Horning suggests in his report that one should get this information by talking to people on the ground for the Non-Forest to Non-Forest and the Forest to Non-Forest sub-classes.

Relying on the word of local villagers for validation introduces great opportunities for error. It may also greatly increase the training needs for the field crews doing the ground truthing. They would need to gain the trust of local villagers and would need to judge the truthfulness of information provided by local villagers. They would need to be accompanied at each site by villagers fully knowledgeable about the land use/land cover in 1993.

This problem can be partially resolved if one can develop accurate biophysical indicators of the age of tavy and fallow fields – indicators of the number of years that have passed since a given site was first cleared from the natural forest. Ground truthing consultant Pierre Berner feels relatively confident that such biophysical indicators can be developed. Biophysical indicators could include:

- Presence of dead logs on the ground or still standing in a vertical position;
- Presence and condition of tree stumps;
- Species composition of the fallow vegetation;

The indicators will first have to be developed by the ground truthing consultant using tavy fields and fallows of known age at a variety of sites in the three corridors. Then the field crews will have to be trained in the identification and use of these indicators.

Even if good indicators can be developed, field crews will undoubtedly encounter borderline sites where the indicators aren't precise enough to determine accurately if the site was Forest or Non-Forest at the time that the 1993 image was captured. Villages may be able to provide precise dates. However, if there is significant uncertainty, the sample should be dropped and replaced with another.

APPENDIX A: Options for Procurement of Geo-Referenced Aerial Imagery For Validation or Characterization Reference Data

Introduction Gathering characterization and/or validation reference data from the air can greatly reduce the time, and perhaps the cost, of these operations. Reference data can be gathered from the air by simple observation, but it is much better if data is recorded in photographic form or through some other type of imaging system. Images provide a permanent record that can be used at any time to document what has been done.

Two types of aerial imaging systems were investigated. Ideally, one would use an imaging system that has a built in global positioning system (GPS) that records latitude and longitude simultaneously with the image. We will call such a system a geo-referenced aerial imaging system. If such a system is not available, a second-best alternative would be to rely on the airplanes GPS system to locate specific sites where one wishes to obtain reference data. One would then take aerial photographs, digital images, videography or other images of these sites. This methodology is less precise but may still be usable if those conducting such overflights are properly trained and experienced.

Local Availability of Geo-Referenced Aerial Imaging Systems   We sought to obtain information on the possibility of local procurement of aerial photos or aerial digital images for use for characterization and/or validation reference data. Frank Hawkins had learned that FTM might be properly equipped with a geo-referenced GPS linked camera system. Information was obtained by telephone from Mr. Herilalao Nary, Directeur de l'Information Géographique de Base du FTM, and from Mr. Rabé in the Departement de Base de Données. Key points from these conversations are summarized as follows:

- FTM has a 9 x 9-inch metric mapping camera equipped with an accurate geo-referencing system (trajectographie, in French), but they have no suitable airplane available in Madagascar. The camera weighs 250 kilograms and can only be used in an airplane equipped with a suitable belly-hole. Mr. Herilalao said there is very little prospect that a suitable airplane will be available in the near future – in the next few months.

- FTM's camera system, when used properly, can be accurate to within a few meters horizontal distance – an accuracy that would be fully acceptable for both characterization and validation reference data. However, even if the camera were functional, metric mapping photography is quite expensive and of much higher quality than what is needed for characterization and validation – a bit like killing flies with a shotgun rather than a flyswatter.

- Neither Mr. Herilalao nor Mr. Rabé knows of any other business or operator that is equipped with a geo-referenced camera or suitable imaging device. Mr. Rabé said there used to be a private business that had a system, but they have gone out of business. Mr. Herilalao said that one might be able to find a supplier from Réunion or South Afrrica. It appears that chances of finding a supplier in Madagascar are not good – but one should continue to make inquiries.

- Frank Hawkins reports that Jim Rowland of USGS mentioned the possibility that USGS could possibly loan a geo-referenced digital camera system for use in forest cover analysis. The system is reported to cost about $5000. I told Mr. Herilalao about this system and asked him two questions:

  1. If we could obtain the loan of the USGS system, would FTM be potentially interested and available to conduct the needed overflights for PAGE?
  2. If it could be shown that there is a significant level of demand for this type of imagery, would FTM be potentially interested in acquiring their own imaging system.

  Mr. Herilalao said that he, personally, would be very interested in either of the above options, but that he could not speak for FTM upper management.

- Option 1, directly above, would be a very short-term solution to PAGE's need for collecting field reference data. However, it might be justified if FTM or another private sector business was interested in testing the system in view of equipping themselves with their own system.

- The e-mail address for FTM is ftm@dts.mg

Purchase of a Geo-Referenced Camera System

Given the lack of any suitable camera system in Madagascar, and given the moderate price of suitable systems, PAGE should seek to purchase their own system, or to assist FTM or another private business to procure such a system. This second option would need to be done with an agreement that the services of the system could be chartered by PAGE and others doing forest cover analysis. The second option should be viewed as clearly the preferable option.

A suitable camera system would probably cost on the order of $5000. Such a system should be accompanied with a system that will allow one to correct for roll, pitch and yaw of the airplane carrying the camera. This may run approximately another $5000 (personal communication with Mr. Horning). Mr. Horning has said would be most interested to work as a consultant to research suitable systems, assist in procurement and, as needed, to assist in training in country in the use of the system. USGS would probably also be able to provide such assistance (this consultant has not yet been able to make contact with Jim Rowland at USGS).

APPENDIX B: Geo-Referencing Accuracy Considerations

It is critical to have accurate estimates of error for X & Y (latitude and longitude) geographical coordinates for the validation reference data. Possible sources of error are the following:

1. The error between the image and map coordinates of pixels compared to their true standard map projection coordinates. The Jean Laborde projection is the standard mapping projection for Madagascar – used for all topographic maps. The Jean Laborde is very similar to the Oblique Mercator projections – maximum difference of one meter for any pair of coordinates.

Horning reports (personal communication) that the reference imagery (the 2000 images) have an RSME (root square mean error?) of 50 meters, although, in general, the error is considerably less than that.

2. The error in the co-registering (superpositioning) the 1993 image and the 2000 image.

Horning estimates the error of the final product (the forest cover loss maps) to be about 50m RSME.

3. The error in the geo-referencing for aerial photography flown/obtained? At this point in time we don't have access to a camera system with a built in geo-referencing system. If such a system can be accessed for use, it will be critical to have an accurate estimate of average and maximum errors in the geo-referencing of the aerial photography. A sizable geo-referencing error (even on the order of 300 meters) may be acceptable for obtaining characterization data for large blocks of homogeneous cover types – especially for large blocks of Forest. Maximum allowable error must be much, much smaller for the validation of sample points in areas of mosaic between Forest and Non-Forest types – unless other ground features from the imagery or from the forest cover change map can be used for geo-referencing sample points on the photography. One needs to consider the total amount of error from multiple geo-positioning error sources when determining whether or not one is within acceptable error limits for locating validation points.

Question for Horning: Given your estimates of geo-referencing errors from 1 & 2 above, what is your estimate of the maximum allowable Type 3 error for this exercise?

Horning's response: "This is a tough call, but I would say 300m should be okay as long as there are other features I can use to position the study site."

- The error in transposing the position of validation sample points from the cover change map to aerial photos that will be used in the field.

Question for Horning: Is it not true that this error will be different for each individual point and will vary with a range of factors including the type of field reference points available, the quality and scale of the photography and the skill of the technician making the transfer?

Horning's response: "Yes."

- The error of the hand-held GPS unit used by field crews for locating sample points.

Question for Ned, JMD others: How does one know what the amount of error is for a given GPS unit? What factors determine the amount of error? How much of the error is built in to the technology of each unit? How much depends on the individual using the GPS unit?

Horning's response: "There are published errors for different GPS units and methods. To be sure though you would need to do field checks and that's probably more that(n) we want to get into."

Study specific questions for Ned:

1. In the May 1 report, one specifies that the 2000 image was ortho-rectified with a published accuracy of 50 meters root mean square error (RMSE). Does this mean the average positional error of each pixel on the image is the square root of 50 meters or just over 7 meters horizontal distance in comparison with the Jean Laborde coordinates? Or is the average horizontal error equal to 50 meters? Does ortho-rectification involve image warping based on identifiable surface features that can be located on both the image and on a topographic map? Does the error depend partly on the skill of the person choosing these points?

Horning's 1st response: "The calculation involves taking the mean of the squares of the errors and then taking the square root of that."

Hagen's interpretation: The average error in horizontal distance is 50 meters.

Horning's 2nd response: Orthorectifying involves eliminating terrain distortions. In this case the ground control from the images came from the ground control reference database that is maintained by NIMA (the ex-defense mapping agency) and automated methods were used to match these points with points in the image. There was not a lot of user input.

2. "The 1994 image had been projected to the UTM projection.... It was not possible to ortho-rectify....". Why would one use the UTM projection rather than the Jean Laborde? Why was it not possible to ortho-rectify the same way that the 2001 image was?

   Horning's response: "The original image was in UTM. I had no control over that. I was not able to orthorectify the image because I do not have a suitable DEM for the area"

   Note by Hagen: I don't know what a DEM is.

3. "...only simple image warping using control points could be done to register the two data sets.....this resulted in a moderately good image-to-image fit, but the positional errors were greater than one would hope for...because the 2000 image was corrected using three-dimensional data..."

4. Did the fact the two images used occur at the beginning (Nov. 21) and near the end (April 19) of the rainy season cause much for problems in analyzing the images?

   Horning's response: "Yes, This is a big problem, but there was no way around it for this study."

5. Was active burning of tavy fields and of tanety grasslands going on while the November 21 image was captured? Was there a problem with plumes of smoke obscuring image detail over local areas? Were both images cloud-free?

   Horning's response: "Not much smoke but the images had clouds. I created a cloud class (obscured included clouds and shadows) so you should be able to assess the percent cloud cover."

6. The areas classified as obscured are quite large in comparison the size of the areas of forest cover loss. What are the causes? Is it mostly clouds and clouds shadows? Are there sizable areas of shadows cause by hill/mountain shadows in very steep terrain?

   Horning's response: "Yes (it was mostly clouds and cloud shadows) but hill shading was also an issue."

7. Your maximum estimate of error (+/- 15 % at 95%) runs about twice the total amount forest cover loss during the period of study. How meaningful is your estimate?

   Horning's response: "I'm 95% sure that my estimate is within 15% of the true value. This accuracy estimate is only for the forest to non-forest class. I really won't know if this is correct until we get the validation data."

Appendix C: Embryonic List of Cartographic and Image Reference Data

One of the first things to be done is to develop a list of all of the key cartographic and image reference data that already exists that should be useful for the forest cover loss analysis of the key sites.

Imagery (various scales, formats and emulsion of aerial photography, different types of satellite images)

- 1950s 1:50,000-scale black and white panchromatic vertical aerial photography that was used to produce the topographic maps of Madagascar. Can it be ordered through FTM? Who has hardcopies of the three corridors that may be consulted/borrowed? Under what conditions?

- Dana Slaymaker imagery taken for ANGAP. Frank refers to the imagery as videography. In a March 28 e-mail, Ned Horning says that it is small format aerial photography:
  - Who is Dana Slaymaker? When did he fly this imagery? Where is he now? Who does he work for? What are his contact coordinates?
  - Was the photography flown for ANGAP? Why was it flown? Did it just cover protected areas? Who has an index showing the exact areas covered? What areas were covered within the three corridors presently under study?
  - What type of imagery was flown? If small format, was it 35mm? 70 mm? What is the scale of the photography? Is it vertical photography? Near vertical? Oblique? What type of emulsion (film) was used? True color? Normal photographs? Slides?
  - Where is the photography located? Who has copies? Was has the negatives? What are the conditions of access? The costs? Does ANGAP have this photography? In what form? Will ANGAP contribute to this study?

- FTM 9-inch metric mapping aerial photography. FTM should have readily accessible records of all photography that they have flown through Madagascar with the detail on scale, date, emulsion types, etc. They probably have at least partial information on aerial photography flown by others. One of the first things to do is to go to FTM and ask for full information on all photography ever flown over any part of the three corridors under study.

- Landsat Thematic Mapper Imagery used for the IEFN maps – see IEFN Maps below.

- Videographic, low altitude overflights recently conducted in late 2000 by ANGAP. See the report « Survols des Aires Protégées et des Ecorégions – Rapport préliminaire – secteur centre-est – 16 à 18 novembre 2000 ». No author is specified but it is believed to be written by Martin Nicoll. Both Martin and Frank Hawkins participated in these overflights over the USAID corridors. An unsuccessful attempt was made to view some of the videography to assess its usefulness – but the equipment could not be made to work.

- On page 1 of Lucy Foley's report for PAGE, "Mapping Forest Cover in Madagascar", December 2000, Foley makes the statement, "…now that TM images are available at reasonable prices (and old images will be available for free in the next few months)…

  - Is old TM imagery now available free? Foley predicted it would be available free by March 2001. What is the definition of old? Foley's report indicates that imagery captured before (and including) 1995 should be available free – this should be confirmed.

    Comment by Horning: "The 1999/2000 TM data is free. There is also a data set for the 1990 time frame that is free. This is also orthorectified imagery. Other than these two data sets, I am not aware of other publicly available free TM data."

  - Having free imagery available could greatly increase the ability to match forest cover loss analysis with the specific dates of field presence of different USAID/NEAP partners, making the forest cover change analysis much more targeted and meaningful.

- Landsat ETM+ imagery referred to on page 11 of Foley's report. She said it was being purchased by USGS – 23 out of 34 scenes had been acquired by December 2000. Copies are to be made available upon request!

- See also Chapter 4 on Existing Maps and Data Sets on Page 9 of Foley's report.

Cartographic Products

- Forest Cover Maps made from the 1950s panchromatic photography and published in the 1960s (Is this vegetation study by Humbert and Darne, 1965 referred to by Foley on page 11 of her report?) As these maps were done from manual interpretation of the aerial photography, they may be of high accuracy – but this needs to be confirmed!
  - Who has published a critical analysis of the quality/accuracy of these maps?
  - What is the classification scheme used? Can our definitions of Forest and Non-Forest be applied directly to these maps?
  - Who published these maps? Where are they available? In hardcopy? Under what conditions?
  - Have they been digitized? If so, where and under what conditions are the digital files available? (Ask these last questions to Jean-Michel Dufils)

- IEFN (Inventaire Ecologique Forestière National) maps. Produced exclusively (?) from Landscape Thematic Mapper Imagery, mostly from 1993 and '94.
  - Who has copies of the technical report describing the methodologies used? Frank?
  - Was all interpretation done manually?
  - Who has done an assessment of the quality/accuracy of the maps? Is it true that no statistical measure of accuracy was ever conducted?
  - Who has the imagery from which these maps were made? Is it available in both digital and hardcopy forms? What are conditions of access? Do copyright restriction claimed by FTM prevent access to this data?
  - Who as the IEFN maps in digital form? What are the conditions of access?
  - How was groundtruthing done? Did groundtruthing consist exclusively of the collection of characterization data? Do the ground truthing records still exist? Are they available/accessible? Are they organized in a usable form? Was ground photography taken from known points? Was any aerial photography taken by IEFN as an aid to interpretation of the satellite imagery?

- FTM analysis of forest cover change at the same sites covered by PAGE. Frank's March 28 e-mail to Ned Horning specifies that FTM would also measure forest cover loss at fours sites in eastern Madagascar including the three (does this include the control?) USAID priority corridors. If FTM has already conducted this analysis, it could be very instructive to compare their results with

Ned's preliminary classification to identify specific areas where the two analysis do no agree. These could be important areas for gathering characterization reference data.

- CFSIGE and ANGAP have also been doing forest cover loss analyses. Do any of their sites overlap with the three sites under analysis by PAGE/Horning?

APPENDIX D: Ideas on the Forest Cover Change (FCC) Ground Truthing TDY

Roy Hagen
May 27, 2001

1. The idea of measuring forest cover change over a huge area like the Moramanga to Onibe (Zahamena) Corridor would appear to be a rather crude, blunt measure that will probably not prove to be nearly as instructive as much more targeted measures. For instance, looking at the recent initial cover change (1994 to 2000) analysis done by Ned Horning, one can make the following critique.
   - Most of the huge Moramanga Corridor has never been touched by USAID partners during most of the time period covered. There are no reasons to expect a positive change in areas where USAID partners have not been working.
   - The change analysis does not correspond directly to the time periods during which USAID partners were present in parts of the Corridor. Most of the Ranomafana—Andringitra Corridor had no USAID partner presence until the start up of LDI in 1999 near the end of the time period covered.

2. One has the opportunity (especially if old Thematic Mapper imagery is now available free of charge, as indicated in Lucy Foley's report) to conduct change analysis in the specific areas where USAID partners have intervened during the specific time periods during which they intervened. For instance:

   - One could analyze the specific sites during the specific time periods when USAID partners were present on the ground. This presence could be broken down by type of intervention (NFM/CBNFM, ICDP, landscape initiatives, regional planning).
   - It could be broken down by distance from the specific area covered. For PA and forêt classées, one could look at forest cover change within the boundaries of the gazetted area as well as by concentric rings around the gazetted area. One could analyze FCC in rings of 5km, 10km, 20km or other distance around the field sites.
   - One could analyze specific areas that have had the longest continuous field presence of USAID partners (Ankeniheny, Zahamena) or where some of the oldest USAID partner sites have been taken over by the USAID-supported partner ANGAP (Andohahela, Ranomafana, Amber Mountain)
   - FCC could also be done by project (COEFOR, CAF/APN, LDI) and by USAID partner (WWF, CI, Chemonics/LDI).

   All of these types of analysis would be much more instructive in analyzing what works, what doesn't, of lessons learned. It would be more instructive in developing future strategies. It would be more instructive in designing future monitoring of FCC.